DESIGN OF AN INTELLIGENT POSTURE GUIDANCE SYSTEM FOR WORKSPACE SEATING

A Design Thesis Presented to The Academic Faculty

By

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Design of an Intelligent Posture Guidance System

for Workspace Seating

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DEDICATION

To Amma & Nanna for making it possible for me to come this far chasing the dream of becoming a designer, to Ammumma for everything, and to binni, for standing by me for so long.

EPIGRAPH

I have always been interested in understanding how machines work. Trained as a mechanical engineer, up until a few years ago I saw computers solely as complex machines that allowed humans to carry out tasks that required a high degree of accuracy and precise control with minimal effort.

However in the course of studying design at Georgia tech, I was exposed to a new world of computers and software where they could be used much more informally, as tools of creative expression and as carriers of intelligence. It is this exposure that made me look at computers in a new way and fueled my interest in interaction design. I see this project as the fist tangible outcome of that interest.

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I want to thank Professor Abir Mullick for guiding me right from the conception of the project. At the very beginning, he was able to direct my ideas and energy towards solving the right kind of problem, something I feel was very important. His mentorship has contributed immensely to my confidence as a designer.

In the same breath I would like to thank Professor Ellen Yi Do for being the one of the biggest believers in my project and championing its cause at a time when I was about to lose hope. Without her encouragement, passion and above all, her approachability as a teacher, I would not have been able to come this far.

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SUMMARY

Seating is an integral part of work environment. When people are at work, they often sit in chairs for long periods of time without changing postures. This results in reduced blood circulation in the body, especially in the buttock-thigh area causing muscle fatigue, pain and discomfort. Ergonomically designed task chairs adopt a passive approach to guiding people into better postures by providing adjustability inside the chair. However most people do not adjust their chairs because they fail to sense the need for changing posture. They are left to sensing the need to change posture through guesswork or extreme discomfort. This thesis proposes a new system to address this problem by sensing static posture in a seated person with the use of electronic sensors embedded in the seat, and by providing interactive feedback to static posture via sound, light and tactile channels. The new technology is an sensing-feedback mechanism embedded in a chair, that allows people to receive postural information and make body adjustments periodically to avoid pain and discomfort caused by prolonged seating.The feedback mechanism was tested with four subjects to determine its efficacy in generating posture change through pressure relief and user feedback was gathered in order to design the final prototype.

CHAPTER 1: BACKGROUND

1.1 Seating and Posture Change

1.1.1 Sitting as a dynamic activity

The presence of a chair and a desk suggest to us intuitively, an environment to do work. Over a period of time, the tools of work have changed. From pen & paper, we have shifted to using computers, keyboards, mice and phones to accomplish work tasks. This change has reshaped the environment of work as well as our own work habits. Increasingly, we find ourselves sitting for hours at end typing away at the computer. Or we lean back to watch content and communication come alive on a screen. Either way, the use of computers has changed how we experience work , which in turn, has changed how much physical effort is needed to do our everyday tasks. Seated work has made us sedentary. A task chair's primary function is to support & stabilize the sitter's body through the different postures required for the person to work. Existing chairs function well at physically supporting us in many postures, yet most of us end up with lower back pain, numbness and discomfort at the end of a work day.

1.1.2 Body posture change as a way to attain comfort

Contrary to popular belief, sitting is not a static condition and there is no one seated posture that is comfortable over a prolonged period of time. The constant need to adjust body posture makes sitting a dynamic condition and confirms the need to build-in many comfortable postures in one seating design.

A change in body posture affects the work triangle, which in turn demands body adjustment. Frequent body posture adjustment is called fidgeting, an unconscious state of body movement. While fidgeting is a constant part of sitting, posture change is necessary to relieve compressed soft tissues in the buttock and the thigh area, restore blood flow, relieve pain and attain comfort, while being seated.

1.1.3 Inability of seated workers to maintain posture change.

When engrossed in work, a worker often overlooks the body's need to fidget and restore blood flow to compressed tissues. Also due to age, physical ability, mental health and poor concentration, seated workers often fail to change posture leading to stress, strain, chronic back pain and spinal disorders.

The inability of people to maintain posture change in seated and recumbent positions can also cause discomfort & injuries. For example, in case of patients in hospital beds, the inability to turn from side-to-side excessively compresses soft tissues and leads to bed sores or pressure ulcers. In addition, people with diabetes and people with neuropathy, hyposensitivity or numbness receive low neural feedback to pain and are unable to heed their body's need to fidget and seek relief .

In all such cases, there is a loss of comfort leading to injuries. Similarly, in cases of work-related sitting, when people are unable to change posture, they experience back and neck stress and work related injuries.

1.1.4 Posture induced pressure

According to Paul Branton [1], About 75 percent of our body weight is supported on 4 square inches of our pelvic bones that make contact with a seat surface.These bone ends are called Ischial tuberosities. This puts an enormous amount of pressure (ranging between 45-60 psi depending on our body weight) on the the skin and tissues sandwiched between the pelvis and the seat surface reducing flow of blood into the surrounding parts of the body. (See fig. 1)

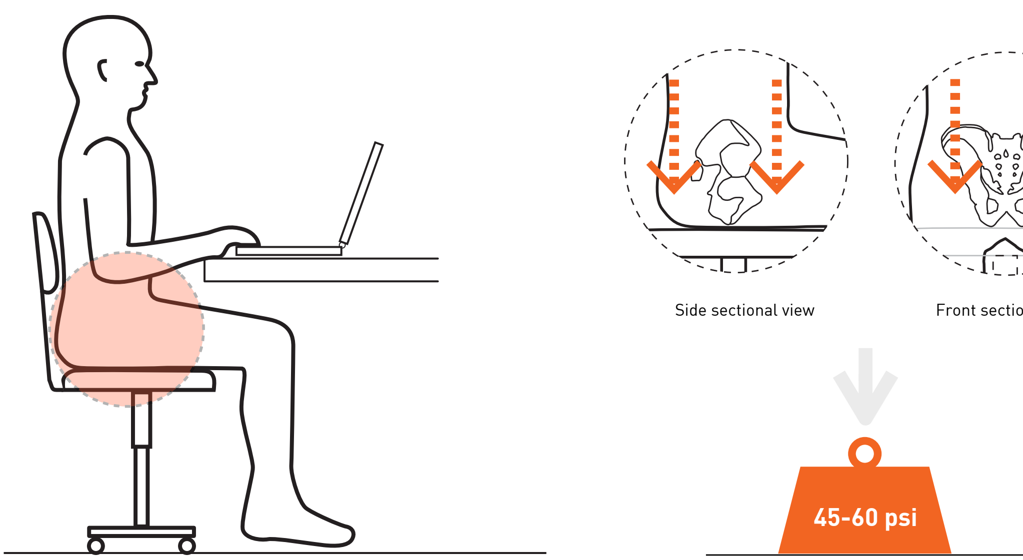

Figure 1 : Posture induced pressure

Another observation made by Branton that is worth mentioning is that sitting in any posture for a length of time requires our body to stabilize itself through the coordination of many muscles. Over a period of time this results in muscular stress that causes pain, numbness and discomfort. Our body naturally tries to relieve this stress by sensing the need to change posture.

<u>1.1.5 Importance of receiving postural feedback</u>

For every seated posture there exists a range of comfort. Maximum comfort is achieved immediately after a posture change, and then comfort gradually diminishes over time. At the point of minimum comfort, the seated worker detects the need to change posture. It is well know that those engrossed at work often overlook their body's need to change posture. Similarly, aging workers or users with medical conditions such as diabetes induced peripheral neuropathy & hypo-sensitivity among other neurological disorders are unable to sense pain and discomfort caused due to sitting. These sensations are vital information that the body's somatosensory system uses to achieve postural correction. As we age, impairment of cognitive function and reduction in sensory input occur naturally and contribute to the inability to naturally change posture. Therefore information required to trigger posture change gradually becomes inaccessible to us either by age or by circumstance of work.

Contemporary workspace seating design has overlooked the need to fill this informational void. The dominant approach to chair design has been to provide comfort by supporting many postures through the use of adjustability built into the chair. Most office chairs now offer under-the-seat controls to make backrest,

Figure 2 : Contemporary workspace seating designs

headrest, seat height and armrest height adjustments. But a corporate study done by Herman Miller has shown that chairs are not adjusted properly because users don’t know how to adjust them. The majority are not adjusted at all [26]. In any case, this approach to seating design has proven to be largely dependent on the workers knowledge of the need to change postures and and move to better postures, leaving the worker to adjust the chair and seek comfort through guesswork. This is a passive approach to achieving postural change in seated workers.

There is a need for workspace seating to be more active in guiding the user towards recognizing discomfort, changing posture, reactivating blood flow, and provide comfort.

1.1.6 History of active seating

The need for a chair to provide postural information that will require users to make seating corrections has not been adequately explored. This study intends to develop seating surface that will sense postural stress through the body weight and sitting duration and inform users to make body posture change and prevent problems associated with static postures. In our design of workspace seating, we will adopt an integrative approach, that is, the seat will support the body and through use of sensors and feedback, inform about the postural stress to the user. (see fig. 2)
There have been a vast number, perhaps even thousands, of workspace seating designs produced in the past decades. Even now, we see new chairs being introduced every year. Some of them introduce innovative materials to make the task chair more comfortable, some introduce new processes of building a chair to streamline its production, and some others add adjustability and mobility to make it more appealing to our lifestyles.

In the process of designing a chair, the designers learn a lot about the human body and its behavior in sitting and working positions. This knowledge (mostly of ergonomics) is finally manifested in chair design in different ways like the geometry of the chair's structure, or its controls, or of its composition.

But in order to make full use of this codified ergonomic knowledge effectively, one is expected to know how to "operate" it. Operation in this case would be for a person to continually adjust the chair to suit his or her body and the work being done. But it is a known fact that few people ever adjust their chairs or are even aware of the existence of the controls.[26] So for the most part people are unable to access the ergonomic knowledge due to a lack of awareness of a chair's full fledged function.

Mike Kuniavsky [2] in his essay "The Smart Furniture Manifesto" argues that this way of designing chairs is an antiquated approach to work and its result is unintelligent furniture. According to him, our chairs have access to a vast amount of information about us, our work and our environment, but they rarely make use of it in order to help us sit better. Given the capability of today's sensor technology, information like our weight, our seated posture, our orientation with respect to the desk along with what kind of work we perform can be easily extracted by the chair and used to guide us into better seating habits.

1.1.7 Prior work done in posture sensing and feedback.

To begin this research, existing literature was surveyed regarding projects that were concerned with posture sensing, classification and guidance. There has been a significant amount of research done in the area of seated posture sensing and classification in the area of workplace accommodation, wheelchair-based pressure alleviating cushion design and cognitive ergonomics over the past few decades. (See figure 3) Some notable examples include The Sensing chair, The Sensitive chair and the Sense chair along with the more recent Vibrotactile chair

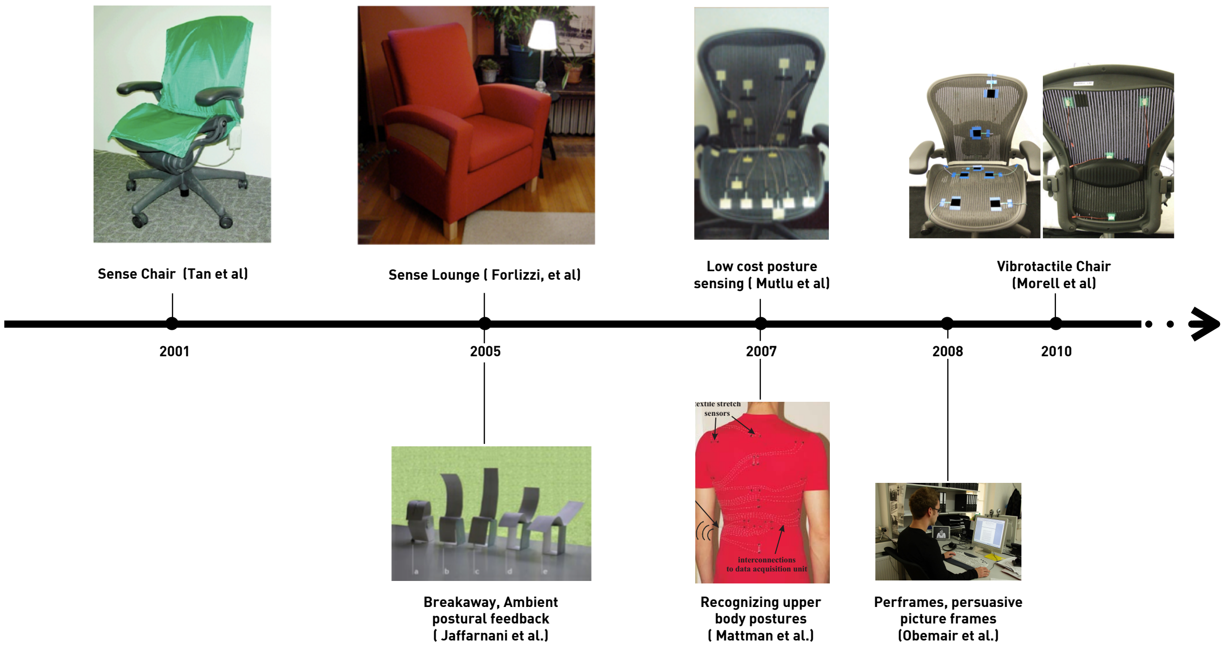

Figure 3 : Timeline of various posture sensing and feedback projects

The objective of majority of the projects surveyed can be classified into one or a combination of the following -

a) Detect the range of seated postures using electronic pressure sensors embedded in the seat pan and/or the backrest with a high degree of accuracy.

b) Classify the range of sensed postures and articulate the variations.

c) Provide multimodal feedback to the sitter when his/her posture deviates from the fixed set of sensed or programmed postures.

I would like to mention three of these earlier projects as they are relevant to my efforts.

Sensing Chair : The Sensing chair (2001) [3] was developed by researchers Hong z. Tan at the Purdue university Haptics Interface Research Lab. The objective of this chair was to detect seated postures and to model and classify them. The chair could also detect slouching. In order to do this, it was equipped with two commercially available Tekscan sensor array sheets having 42x48 pressure sensing elements. One of the sensor sheets was draped over the backrest while the other was placed on the seat pan. (See fig. 4) Together, the sensors detected the pressure distribution over the seat pan and the backrest. This distribution was visualized as 2d as well as 3d pressure plot diagrams. However there was no posture feedback that was provided to the sitter.

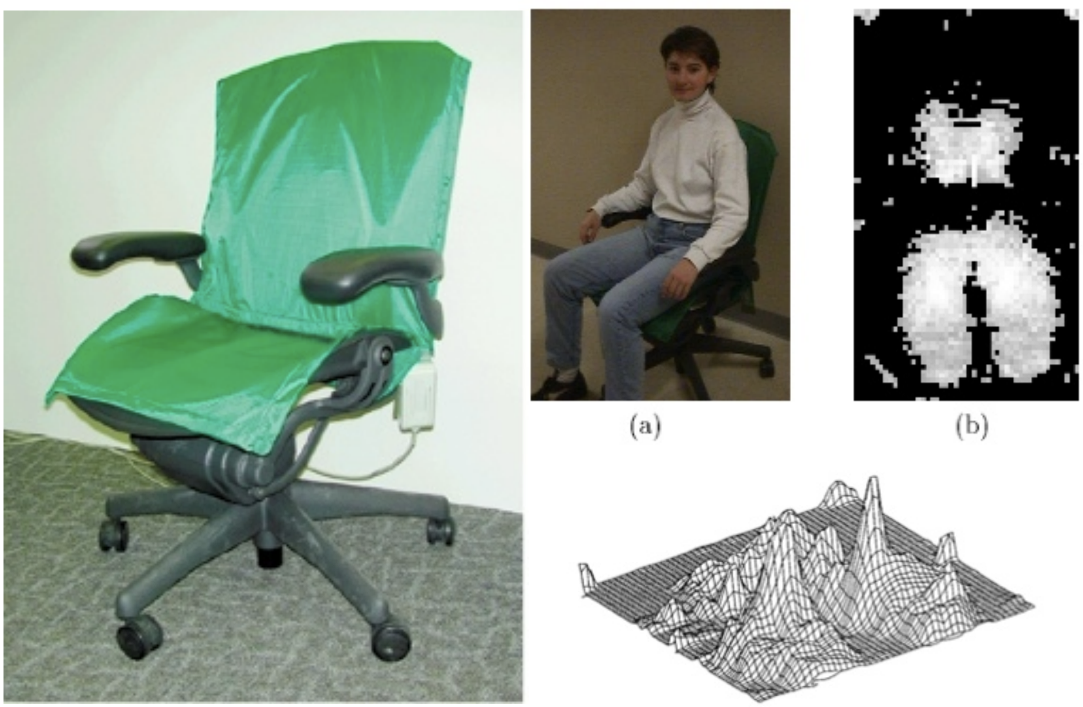

Figure 4 : Sensing chair, Hong Z. Tan et al, 2000-2001

Vibrotactile Feedback System: The second relevant project is the Vibrotactile feedback system developed by Zheng and Morell [4] at Yale University. This system

used seven force sensitive resistors on the seat and the backrest to determine the pressure distribution of the sitter and consequently his/her posture. Using the sensor data, the feedback system then determines if the posture of the sitter deviates from the set of predetermined “safe” postures. Upon deviation, six “tactors” (vibrotactile effectors) present at the location of the pressure sensors, generate subtle vibrations to make the sitter aware of the deviation and trigger posture correction.
The sitter has the ability to increase or decrease the intensity of vibration of the tactors to suit his threshold.

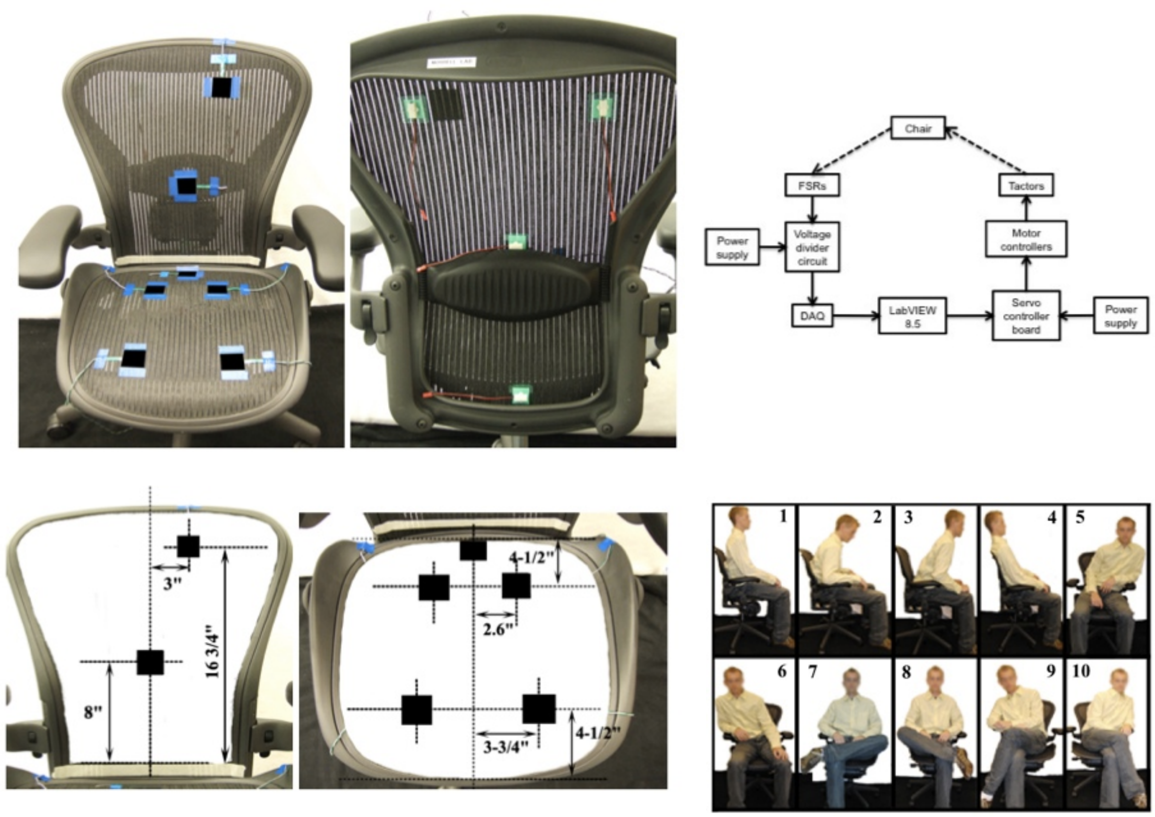

Figure 5 : A vibrotactile approach to postural guidance Ying (Jean) Zheng,John B. Morrell

Breakaway system : Finally, Breakaway [5] is a posture feedback system developed by a team of researchers at Carnegie Mellon University led by Nassim Jafarnani, Jodi Forlizi, Amy Hurst & John Zimmerman in 2004. Breakaway system consists of a miniature chair “model” that serves as an abstracted ambient display of a person’s seated posture in a chair. The chair is instrumented with pressure sensors that detect the presence of the sitter and transmit this information to the chair model. Once the sitter remains seated for an extended period of time of time, the model makes use of a servo motor to change its ‘state’ from straight to slouching. This is one of the novel ways of displaying whether a person has been sitting in one position for too long without obstructing his/her work or vying for their visual attention. However the sitter had no control over the feedback’s nature or magnitude.

There are other projects that have tried to address the need to provide posture guidance through pressure sensing systems but have not been dramatically different in their approach from these 3 projects. Table 1 summarizes related work that was discovered in the literature search. Seven of the ten studies provided postural feedback to the user. (See table 1)

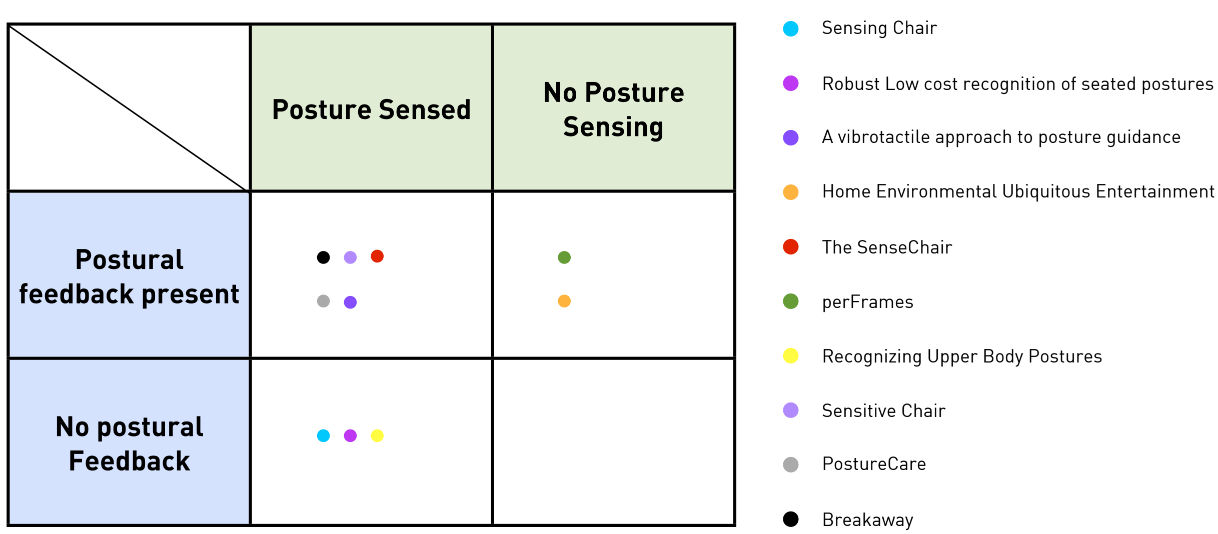

Table 1 : Table comparing of various posture sensing projects, (Jalasutram, 2011)

Also worth considering is among the studies that provided postural feedback to the user, only one (PostureCare) used more than two feedback channels. However it did not provide the user with control over the feedback generated. Table 2 compares the different posture sensing projects based on the feedback modes they employed to provide postural feedback.

	Audio	Visual	Vibrotactile	Tangible Form	User control over feedback
Sensing Chair			-NA-		
Robust Low cost recognition of seated postures			-NA-		
A vibrotactile approach to posture guidance			✓		✓
Home Environmental Ubiquitous Entertainment	✓				✓
The SenseChair	✓		✓		
perFrames		✓			
Recognizing Upper Body Postures			-NA-		
Sensitive Chair	✓			✓	
PostureCare	✓	✓		✓	
Breakaway				✓	

Table 2 : Comparison of various posture sensing projects based on the nature of postural feedback, (Jalasutram 2011)

<u>1.1.8 Problems with previous approaches to posture guidance.</u>

There are several problems with the previous approaches to posture guidance like the design of the sensor array, the appropriateness of feedback.

1. Design of the Sensor array: Previous approaches to posture guidance used a combination of off-the shelf-sensor arrays and individual sensors to sense pressure distribution of seated users. In almost all the approaches the pressure mats were

used initially to understand the pressure exerted on the seat-body interface only to be later replaced with individual sensors placed on the seat pan at the appropriate locations. The pressure sensing mats that were used initially in the studies are commercially available, but are expensive (up to $1500). They are better suited to use in clinical studies and healthcare environments but not in workplaces or home environments. In addition, they can be difficult to setup and program without engineering expertise. As mentioned, in almost all the studies, the pressure mats were later replaced with individual sensors. However there was no investigation into incorporating the individual sensors as an integrated package. Why can't the sensor array be well designed for consumer use?

2. Lack of multi modality of feedback : While some studies studies used the sensor information only to accurately determine the pressure distribution corresponding to a particular posture (Sensing chair, and create new classifications of postures.
3. Approach to postural feedback : Projects like the Sense chair, the Vibrotactile chair and the Sensitive chair have feedback systems to alert the sitter when the posture is static and/or deviant from a pre-set typology. The assumption here is that a pre-determined set of seated postures are 'safe' for the body and so the sitter should be encouraged to adopt one or more of these postures more often. Therefore deviant postures are discouraged with the use of feedback. This is counter-intuitive to much of the recent literature in ergonomics and human factors that states that poor posture and lack of postural variety cause musculo-skeletal disorders It is in fact any

deviation from a static posture that needs to be encouraged. As the noted chair designer Peter Opsvik [6] points out "The best posture is always the next one."

4. Feedback magnitude : our lives are already loaded with stimuli. As stated by Naoto Fukasawa [7], "Too much stimulus inevitably interrupts the unconscious flow of activity by provoking conscious attention." Instead, there is a greater need for information/feedback displays to blend into the flow of everyday life, so information can be accessed almost unconsciously. Therefore the type of feedback and its magnitude is of critical importance with regard to its fit with the sitter. Previous systems provided feedback whose magnitude ranged from somewhat invisible (impercieveable) on one end of a spectrum to obtrusive and annoying on the other end.(See fig.6)

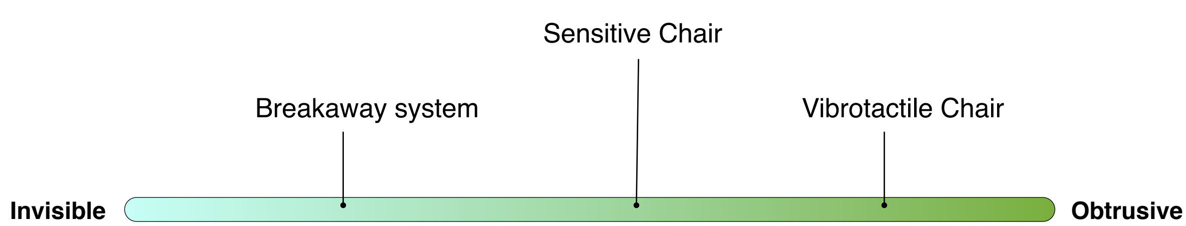

Figure 6: Comparison of different postural feedback systems based on their obtrusiveness

1.2 Interactivity and Health

1.2.1 Interactivity and Interaction

Interactivity can be defined as the "*quality of people or objects that allows them to influence one another through the exchange of information"*. The basis of all interactivity is this ongoing communication between two or more "beings". I use the word 'being' instead of people or actors because I think for any person or object be interactive with us, they have to have a living consciousness of themselves, of us and the environment surrounding us.

Interaction is the process though which this communication is carried out. In the case of designing interactive artifacts, one of these actors or "beings" could be a man-made object (physical or digital) while the others could be a person.

According to Nathan Shedroff [8] in his seminal work *A Unified field theory of design*, the experiences we go through could be placed on a continuum of interactivity, (See fig. 7) where the extremes range from passive to interactive. This suggests that highly interactive experiences provide generous feedback, control, adaptivity and creativity in communication between the user and the object.

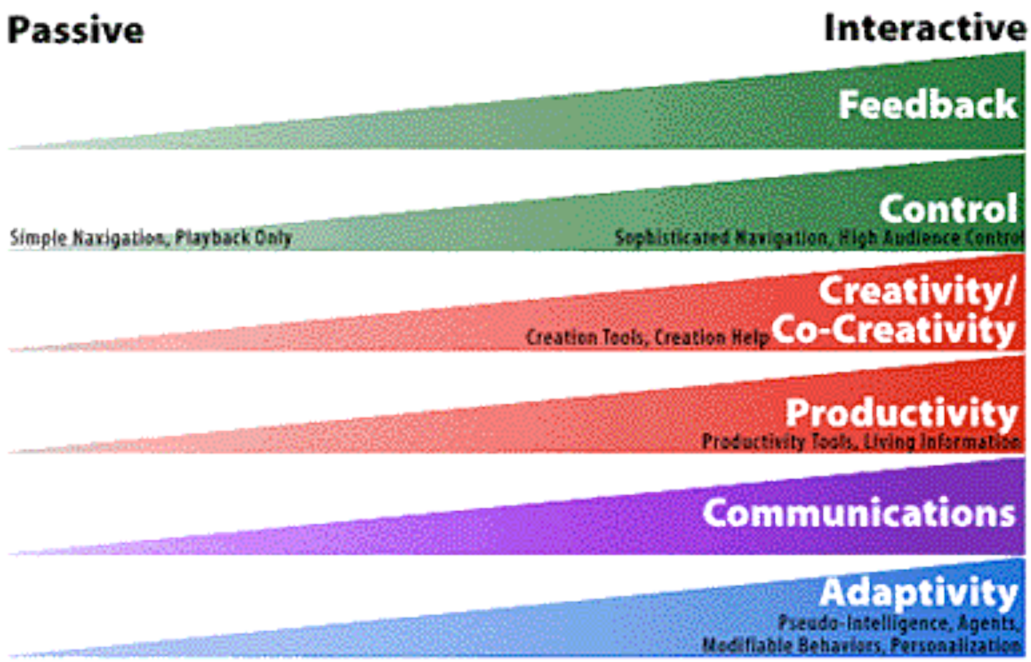

Figure 7 Nathan Shedroff's Continuums of interactive experiences

Dan Boyarski [9], a prominent design educator points out that most human interactions - a conversation, a kiss, a dance, a game or an act of stand-up comedy - are in fact interactive because the participants influence each other's thoughts, words and gestures . Combining these two ideas we can say that

1. Interactivity is a very human quality, and
2. All of our experiences with the people and the environment can be placed on continuum of interactivity depending on how much control & feedback we are offered and consequently how creative or productive we can be because of this experience.

1.2.2 Interaction Design as the design of behavior of the system

Interaction design has been defined by many researchers and designers in different ways. Richard Buchanan[10] defines interaction as the the *framing of the relationship between people* and the objects they use. Another noted designer, Dan Saffer [11] defines *interaction design as something that is mostly concerned with human's interaction with each other through the use of objects*. There is little distinction between these definitions and what Industrial designers do. However, Interaction design is different from other branches of design, in that it is concerned with the construction of an object's behavior over a period of time, as it is in constant communication with its user or the environment it is placed in, or both at once. This nascent field of design is therefore fundamentally independent of any particular medium and draws from the rich traditions of Industrial design, Human factors, and Human computer interaction.

1.2.3 The design of Interactive objects.

The ability of an object to change its behavior with time, user and environment is something that poses dynamic challenges to a designer. Typically, Designers work on objects/media that have some amount of permanence in behavior. For example, a toaster, lamp or a car remain functionally unchanging once they are produced and sold. A graphic designer may design a book, considering that the content inside the book remains effectively unchanged even when read by people of different ages, races and genders. But an interaction designer might want bring in more interactivity into the book, allowing the content to be constantly shaped and reconfigured by the people who come into contact with it while also being changed in the process of interaction.

1.2.4 Role of Interactivity in Industrial Design : Devices that provide feedback & control

When a person interacts with an object, he/she navigates the information contained within the object through one or all of his senses - sight, touch, smell, hearing and taste. The person *experiences* the object and reacts to the *experience*. Traditional fields of design focussed on designing this experience by shaping the product's form, materials, weight, structure, color, texture and so on. In the process of this shaping, the intended experience of using the object gets embedded inside the object by the designer.The product therefore embodies the intended experience of using it.

With a passive product, this embodied experience cannot be shaped by the person who uses the product beyond a certain limit. Products typically make use of modularity and adjustability in the interface to allow for personalization. These allow the user to effectively control the product and receive feedback while doing it. Interactivity is a way for passive products to take this relationship further by allowing them to become aware of the people who use them, and the places they are being used in. This awareness could be termed as 'active intelligence' .

Industrial Designers have for long tried to build 'active intelligence' into the products they design. For example, Achille Castiglioni's Oil and Vinegar containers [12] had a lid with counterbalancing weights that let it open and close just by tilting the container making the interaction playfully interactive. Similarly Jonathan Ive's Hair brush [13] had a spirit level attached to it that allows hair dressers to view the orientation of the comb in space.(See fig. 8)

Figure 8 : Achille Castiglioni's Oil and Vinegar containers and Jonathan Ive's Haircomb

thereby allowing them to control their strokes and get continuous feedback on it.

1.2.5 Role of sensors in interaction design

This study uses hardware sketches to develop the final function prototype of the interactive posture guidance system.Sensors are to an interactive system what our senses are to our mind. Our senses gather information about our world and allow us to constantly evaluate, orient & control our experiences to suit our comfort level. Similarly, electronic sensors can listen in on our use of the interactive system and use that to inform the output of the system.

With the increasing pace of technological development and the growth of computers, sensors have started to be embedded in many products.

Most notably, the new generation of mobile devices have sensors that can sense human presence close by (proximity sensor) , the amount of light in the environment (ambient light sensor), the spatial orientation in which they are used (accelerometer and gyroscope) and even geographic location in the world (GPS). Given the capabilities of these sensors, mobile devices know much more about us and our world and can use this information to become more useful to us.

But the most interesting part of this development has been the incredible rise in the availability and programmability of these sensors to designers and hobbyists with an interest in designing interactive products. New tools such as the Arduino micro-controller (See fig. 9) and Phidgets combined with robust programming environments such as Processing, Pachube & OpenFrameworks make it easier for designers to create operational prototypes of electronic devices. This phenomenon has given rise to a new design method called *hardware sketching*.

According to Fabricio Dore [14], an interaction designer at IDEO “Hardware sketches are the tools or building blocks of technology design. They allow the designer to explore experiences mediated by products or staged in spaces without requiring engineering support during creative phases.”

Like physical models serve as formal representations of an object, hardware sketches serve as functional representations of an interactive system allowing the interaction designer to visualize, communicate and iteratively refine the behavior of the system/object he is designing.

This has propelled a newfound design interest in adding interactivity to everyday objects.

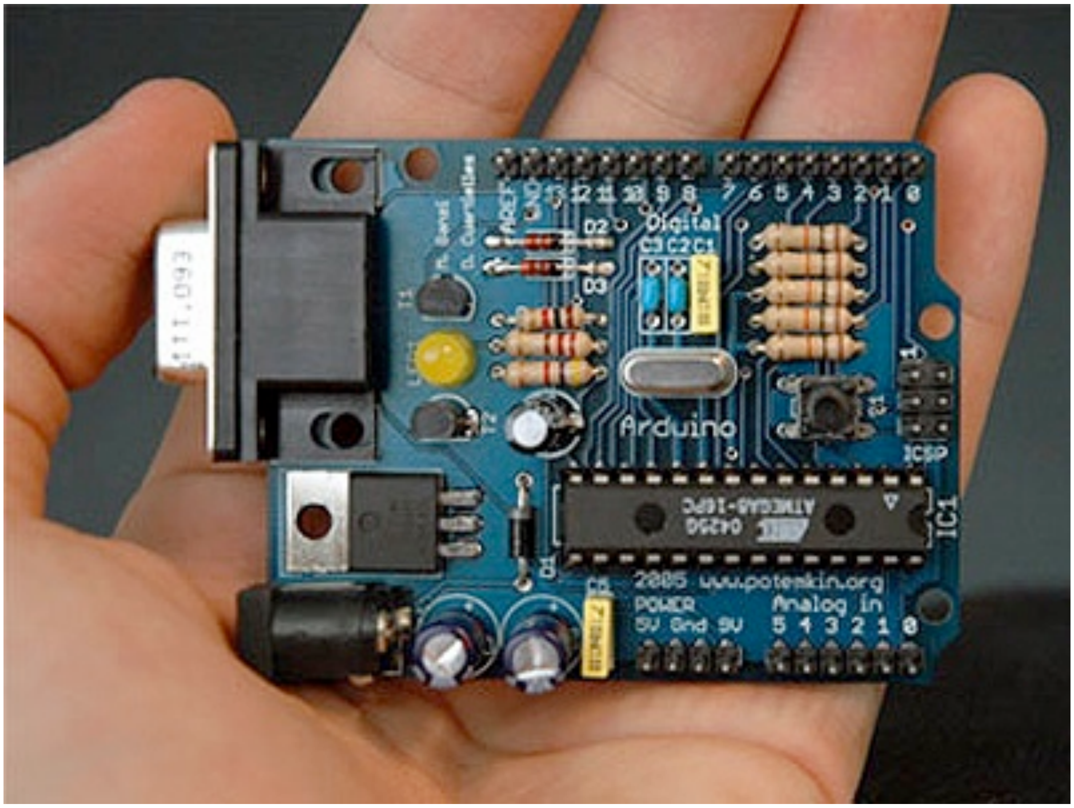

Figure 9 : Arduino chipset

to change how they can behave.

1.2.6 Interactions with physical objects and health

Our interactions with our physical environment and objects in it determines our health to a large extent. Physical objects enable physical activity and so become interfaces between our bodies and the built environment. We interact with a chair to sit on it, a car to transport ourselves, a house to shelter us, clothing to obtain physical comfort and so on. So it is but natural to view these objects as conduits to our health and well-being.

But our relationships with these objects are not always evident or easily discernible, as the objects themselves are passive. By adding a little bit of 'active intelligence' into these everyday objects, we can visualizing the health information embodied inside the physical objects and re-shape our relationships with them.

Recently, a new class of interactive electronic devices have emerged. Mobile Health Trackers, as they are called, are miniature electronic devices that can continuously collect information, for example, your weight, your heartbeat, the distance you've walked in a day, the number of calories you've burned and the hours you've slept. They are designed to be worn on one's body or clothing (apparel / shoes) from where they collect this information unobtrusively.
Nike+ and Fitbit are two such examples of consumer-level devices.

Once this information is collected, these devices can wirelessly transmit ("sync") this information to a webpage, your computer or your phone where you can view this information using digital interfaces and modify your habits accordingly. So health tracking is a way to obtain feedback about one's behavior and use it to self-correct or self-control one's health.

1.2.7 Limitations of current tracking methods.

There are several limitations of current tracking methods, including the lack of compelling visualizations of data, the separation of feedback from context and difficulties with accessing the data from a computer.

1. Lack of lasting visualizations of data.

Health trackers reveal a lot of information about our body's performance that was previously invisible to us. When such a large amount of data is in numerical form, it can be hard to understand. To tackle this problem, computers are used to visualize this information as graphs, charts and other dynamically generated diagrams. This makes it easier for us to understand the data at a glance and spot patterns. While this approach allows us to understand the information, it still does not tackle the larger issue of creating a lasting relationship between a person and his/her body by interacting with health information.

2. Feedback disembodied from context

According to Anind Dey [15] Context is a piece of information that can be used to characterize the situation of an entity In order to provide compelling visualizations of health data, the trackers often transmit ("sync") collected behavioral data to a computer/phone where the user can interact with the information in richer ways. This model of feedback display has two problems associated with it. Firstly the time at which the behavior is observed is not always the same as when the feedback is displayed. For example, users of performance monitoring systems such as nike + are given feedback on their runs after the run takes place, making it impossible for the runner to make changes to his running behavior during the run. Secondly the location in which the behavioral data is collected may be different from where its feedback is displayed. For example. data collected about sleep times is often displayed on a desktop computer screen and not near the bed. This change in context breaks the user's mental connection between the feedback generated and the action that took place making it harder to make changes to behavior in real time

3. Need for computer usage proficiency.

To take the best advantage of existing health trackers, one needs to have access to a computer or a smartphone and be able to operate it. But people with disabilities and older adults who need to track their health may have reduced physical or cognitive abilities that make it harder to use computers or phone. This can reduce access to valuable health data. Thus, there is a need to make this data more accessible and make the interactions with it more natural. One of the ways to do this may be to design new interactive devices that do not need a traditional mouse/keyboard to operate. Instead they function as standalone devices making use of new input paradigms.

1.2.8 Design of Postural feedback system - opportunities

The design of a feedback system poses both physical and digital design challenges and opportunities

Physical design opportunities :

As shown in the previous studies, the use of a pressure sensor arrays is a robust way to detect and identify seated postures. But neither the commercially available pressure mats nor the individual sensor arrays are integrated as a package that is designed to

a. be setup without prior hardware development and assembly experience on the part of the user.

b. be built with care given to overall structure (material and finish)

c. Fit with the wide variety of existing task chairs

d. be built in a way to be portable,since most people adopting static postures are office workers who may need to sit on more than one chair through the period of their employment.

e. be more affordable and usable than the existing products.

Digital design opportunities :

The design of the digital components of an effective postural feedback system would need to satisfy these requirements

a. Postural information made perceivable yet personal

Our posture is an physical indicator of our body's position at any given moment in time. However we are not always aware of our posture. Research done by Philiips [16] shows that it is difficult for office workers to 'see' their posture while at work. There is immense value in being able to perceive our behavior in order to self correct and control it. Sigurdssen and Austin [17] have proved that showing office workers visual feedback to their postures in real-time improved their ability to self monitor their postural behavior and correct it.

b. Need for feedback to be embodied in the immediate environment

According to Paul Dourish [18]

“ Embodiment is the property of being manifest in and of the every- day world. Embodiment constitutes the transition from the realm of ideas to the realm of everyday experience.The setting within which the activity unfolds is not merely background, but a fundamental and constitutive component of the activity that takes place.”

In the case of a seated worker doing computer-based work, the setting is his immediate surroundings which includes his chair, the desk / table, and the tools or equipment on his desk (computer monitor, mouse,the phone, keyboard, paper, stationery etc). The workers posture is directly influenced by his interactions with these physical objects. Therefore his environment is ripe for embodiment of feedback.

c. Multi-modality of feedback : Providing feedback in more than one medium allows for the sitter to choose the best way to receive the feedback depending on his/her immediate state, physical and cognitive abilities and the nature of work that he is doing. For example, a receptionist who is constantly operating the phone might find it useful to receive the feedback via vibration rather than audio.

d.Tolerance of error: For any interactive feedback system it is important that the system be sensitive to unintended and false inputs that can give rise to unexpected output. For this study the postural feedback system should be able to distinguish between ‘near-static’ postures and ‘real static’ postures and provide feedback accordingly. Near-static posture occurs when the sitter exerts a high amount of pressure on the sensors for a very tiny fraction of time (for eg: when sitting down on the seat for the first time) while real-static postures occur when the high pressure lasts for a considerable amount of time.

e.Provision for Sitter control over feedback : The other important aspect of a feedback system is the ability for the sitter to be able to control the intensity of feedback. Each person has a different threshold for being able to sense sound, light, smells, touch and tastes. These thresholds change with age, gender and amount of engagement needed by the work the sitter is doing. So if the feedback provided by the postural guidance system exceeds or does not match the threshold that their context demands, the sitter should be able to adjust it to suit his/her needs.

CHAPTER 2 : METHODOLOGY

The methodology included study of seated workers through observational research, analysis of posture change and pressure relief , followed by prototyping and design of the feedback system.

2.1 Observational Study

The aim of this study was to observe seated people at work in different work environments and document their postures, their use of computers and the relationship between both. This was done in two ways - unstructured observations and structured observation. For the unstructured observations, People were observed while seated and working on campus a the library, several classrooms and several computer labs. Notes were made of their body movements, how often they adjusted themselves in the chairs, and the frequency with which they took a break for their work.

For the structured study, the postural variations of people who have to sit for prolonged periods of time in their workplace were recorded Three female subjects and two male subjects participated in the study. Except for one female subject who was a student, the others were office workers whose work depended on using the computer for the entire duration of a typical workday.

The study began with a short interview followed by video capture of each person working for about 45-60 minutes each. The subjects were asked about their age, gender, their profession, and any medical conditions that affect their seating.

Using the captured video, frames were extracted at the times where the subject made a significant postural change. The extracted frames were composed into mosaics like the ones below to see the movements made by the sitter over a period of time.(See figure 10)

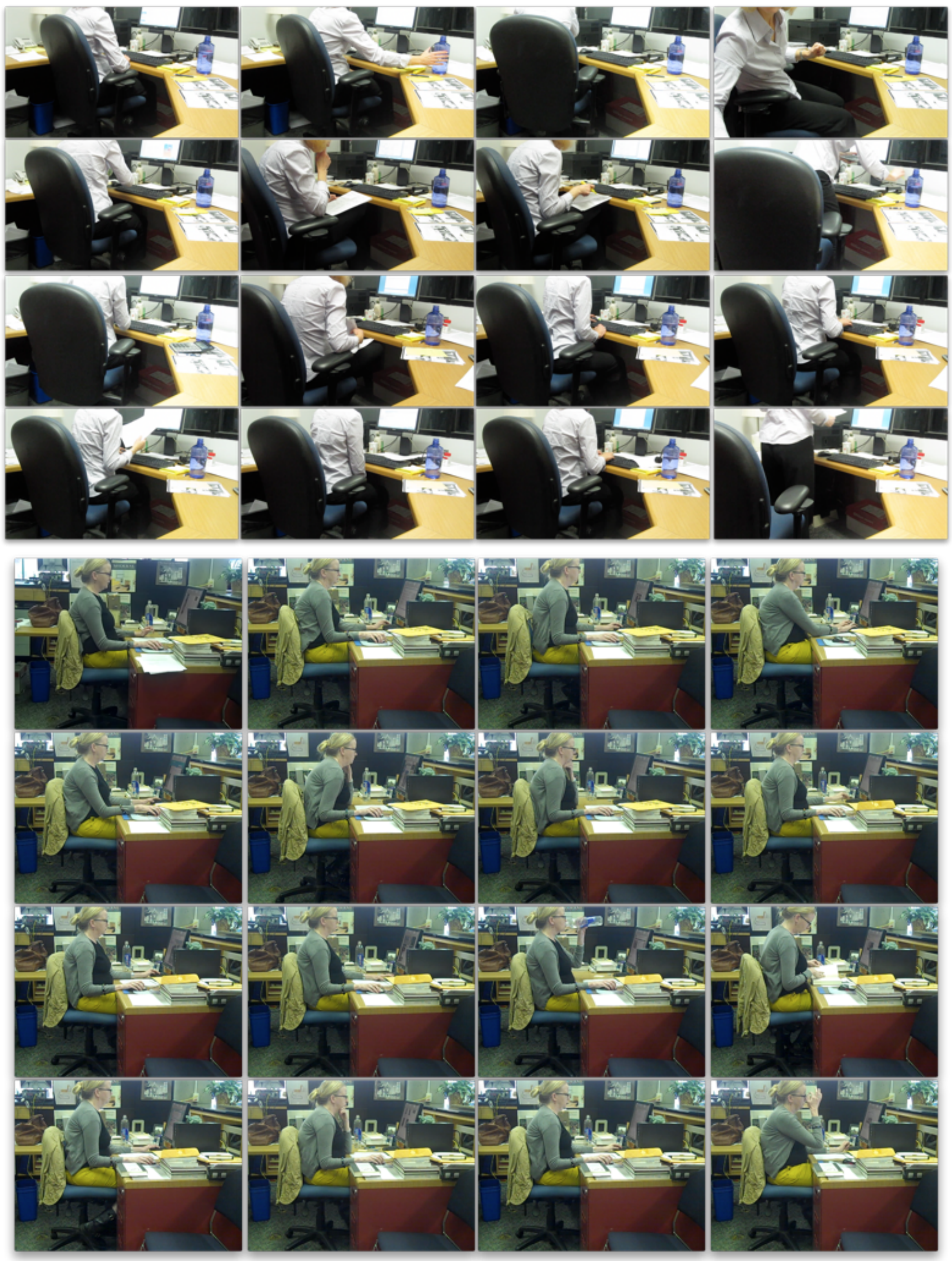

Figure 10 Movements of observed office workers when seated.

Next, all the extracted frames that represented a change in posture wee overlaid to determine the span of posture change that occurred during the period of observation.

Figure 11 Analysis of captured video showing active and inactive areas of the body.

The result of this technique was a composite image that represented the span of posture change exhibited by the subject over the period of observation. The biggest finding from this image was that greatest movement is seen only in the upper body with the subject occasionally leaning forward towards his computer and backward away from the computer. There is hardly any perceivable movement noticed in the buttock & thigh area.

2.2 Measuring the impact of posture change.

In order to understand the relationship between posture change and the change in pressure applied in the buttock-thigh region, we used a Tekscan pressure mapping system that can sense and visualize the pressure at the interface of the body and the seat.

The system consists of a thin fabric-like Force Sensor Array placed on a regular office chair seat connected to a computer running a recording & visualization software. (See Fig.12)

Figure 12 Using the tekscan pressure mapping equipment to measure seat-body interface pressure

a) Pressure mat b) person using the mat c) the pressure profile generated by the mat

A test subject (male, 28 year old, weighing 160 lbs, 5'7" tall) was instructed to sit in the chair with the pressure mapping system and perform his normal computer based work, normally for about an hour at a time. At the same time, two video cameras were used to record his movements from the front and from his side.Two Hour long sessions were recorded. At the beginning of both the sessions, the timing of the video camera recording as well as the pressure mapping system recording was synchronized to begin at the same time.

Later the video recording was analyzed to extract the frames that showed significant postural change, while the pressure mapping recording was analyzed to extract the frames that showed a change in the pressure profiles.

By comparing these two sets of frames, the changes in the subjects posture that caused a movement of the high pressure zones in the pressure profile were identified. An early typology of the posture change movements based on pressure relief events emerged. (See fig. 13)

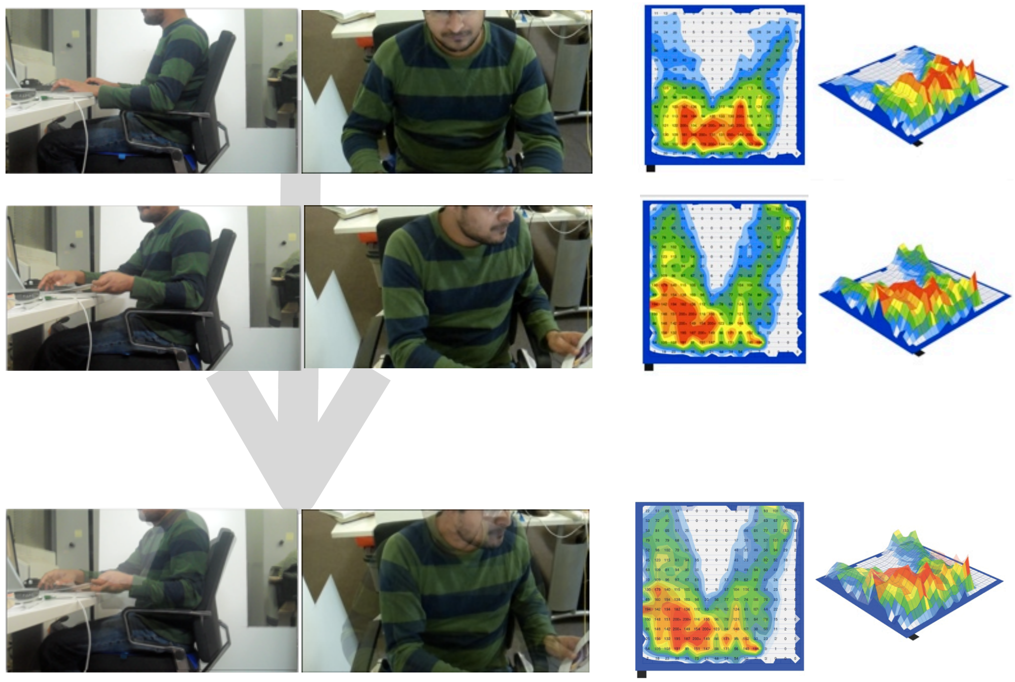

Figure 13 Mapping posture change to pressure profile

Also, upon analyzing the changes in the pressure profiles over the duration of the study, I was able to mark out the area of the pressure map that contained the movement of high pressure points. (See fig. 14)

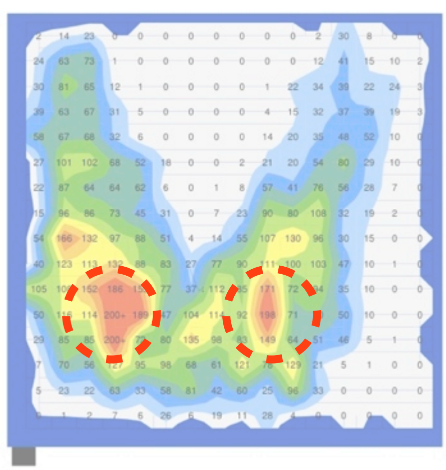

Figure 14 : Areas of high pressure marked to suggest the placement of individual sensors

This information was valuable in the later stage of design to know where to place the individual sensors on a seat so as to sense the points of high pressure on a continual basis.

2.3 Selection of sensors and prototyping.

Based on the information gathered from posture change matched pressure profiles, it was evident that in order to provide feedback to posture change, the pressure exerted by a seated person at the seat-body interface needed to be sensed on a continual basis. A solution was commercially available FSR (force sensitive resistors)sensors. Force sensitive resistors are thin film-like solid state resistors that convert the force exerted on them into measurable electrical signals. These signals can be processed by a microcontroller. FSR's are available in either circular and square shapes. The circular FSR's have a sensable area of about 25 mm in diameter while the square shaped FSRs have a larger sensable area of about 40 mm sides (see fig. 15)

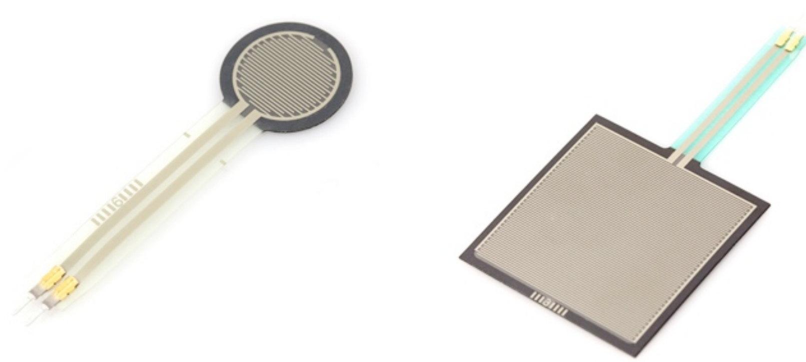

Figure 15 : Circular and Square shaped force sensitive resistors used in the study

To begin prototyping, the sensors were connected to an Arduino Micro-controller which in turn was connected to my computer. I also connected LED's, sound buzzers and vibration motors to the Arduino to act as output devices. The computer was used to program the micro-controller to interpret and convey the input received from the FSR into different kinds of feedback. (See fig.16)

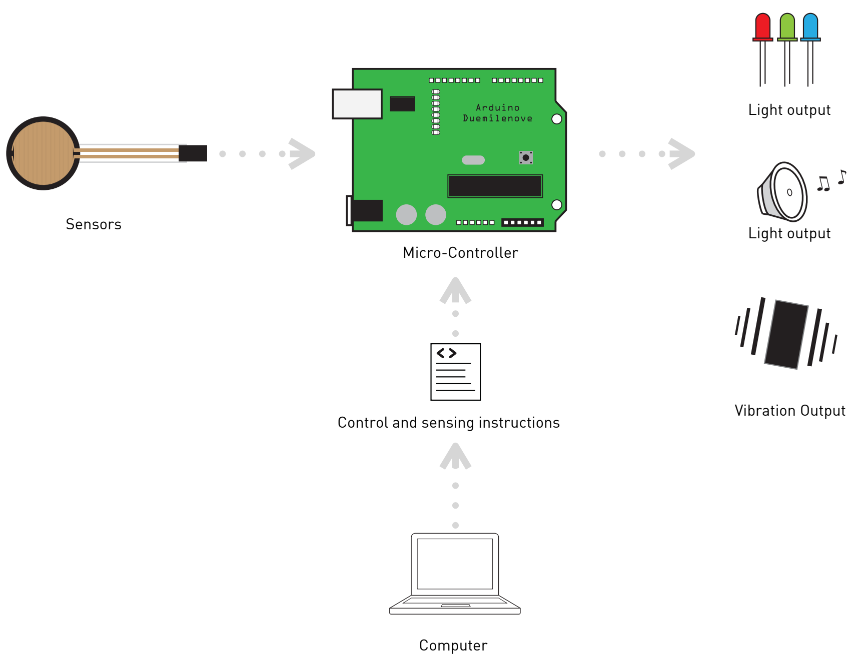

Figure 16 : The system diagram showing the setup used to create the functional prototypes

Using this setup, several functional feedback prototypes connected to FSR input. The feedback modalities that I explored include Sound, visual cues on the computer, standalone LED's and vibration. In total about 10 functional prototypes were made to simulate and learn from changing. (See fig.17)

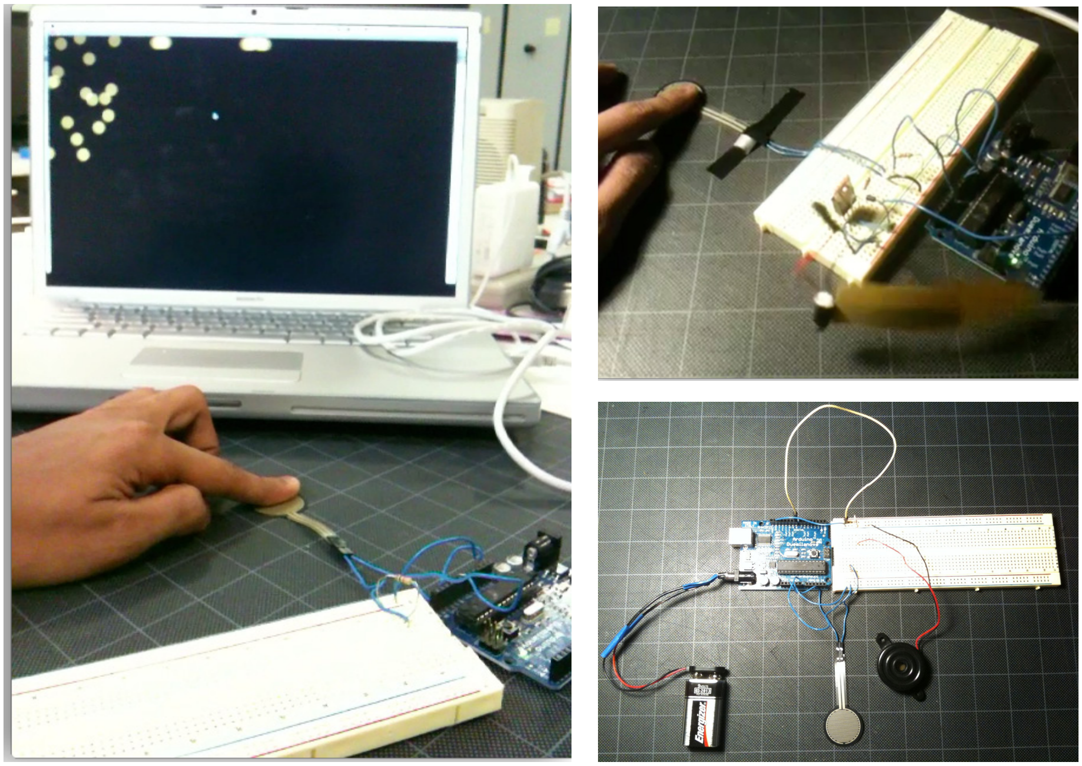

Figure 17 : Different kinds of functional prototypes, clockwise from left, pressure to visual, pressure to vibration & pressure to sound

One of the overarching design goals of the feedback system was to be unobtrusive to the person using it at his/her workplace. With this in mind, some simple informal evaluations with local office workers were conducted in which they were asked for comments. From these evaluations, it quickly emerged that visual feedback for postural change was much less attractive when presented on screen than other kinds of ambient feedback. Also, people tended to like how audio and vibrotactile feedback prototypes functioned but expressed concern over its appropriateness in an office setting.

2.4 Integration of the sensors with the chair

The functional prototypes made use of only a single FSR to simulate the feedback system behavior. In order to be used with a seated person, however, this sensing system needed to be scaled up to detect the pressure exerted by the person over the entire area of the seat pan. Therefore the next stage of prototype builds was to add more sensors to the system and have it integrated with the seat of an office chair.

A regular office chair with seat and backrest made with mesh fabric construction,was used. The mesh fabric allowed for easier attachment of the sensors to the seat surface. Then, 6 sensors were placed on different locations on the chair corresponding to the high pressure zones discovered in the previous phase. (See. fig. 1b)This allowed for accurate sensing of high pressure points at the seat-body interface

Figure 18 : First prototype of the sensing-feedback system

2.5 Refinement of the prototypes

While integrating the sensors with the seat allows for accurate sensing, It ties the sensors to a single chair. This makes it hard for people to use the feedback system with any other chair. Therefore I decided to separate the sensors from the chair, structurally and instead embed them collectively into a mat . This can ensure the accuracy of sensing while allowing for portability of the entire system. (see fig. 19)

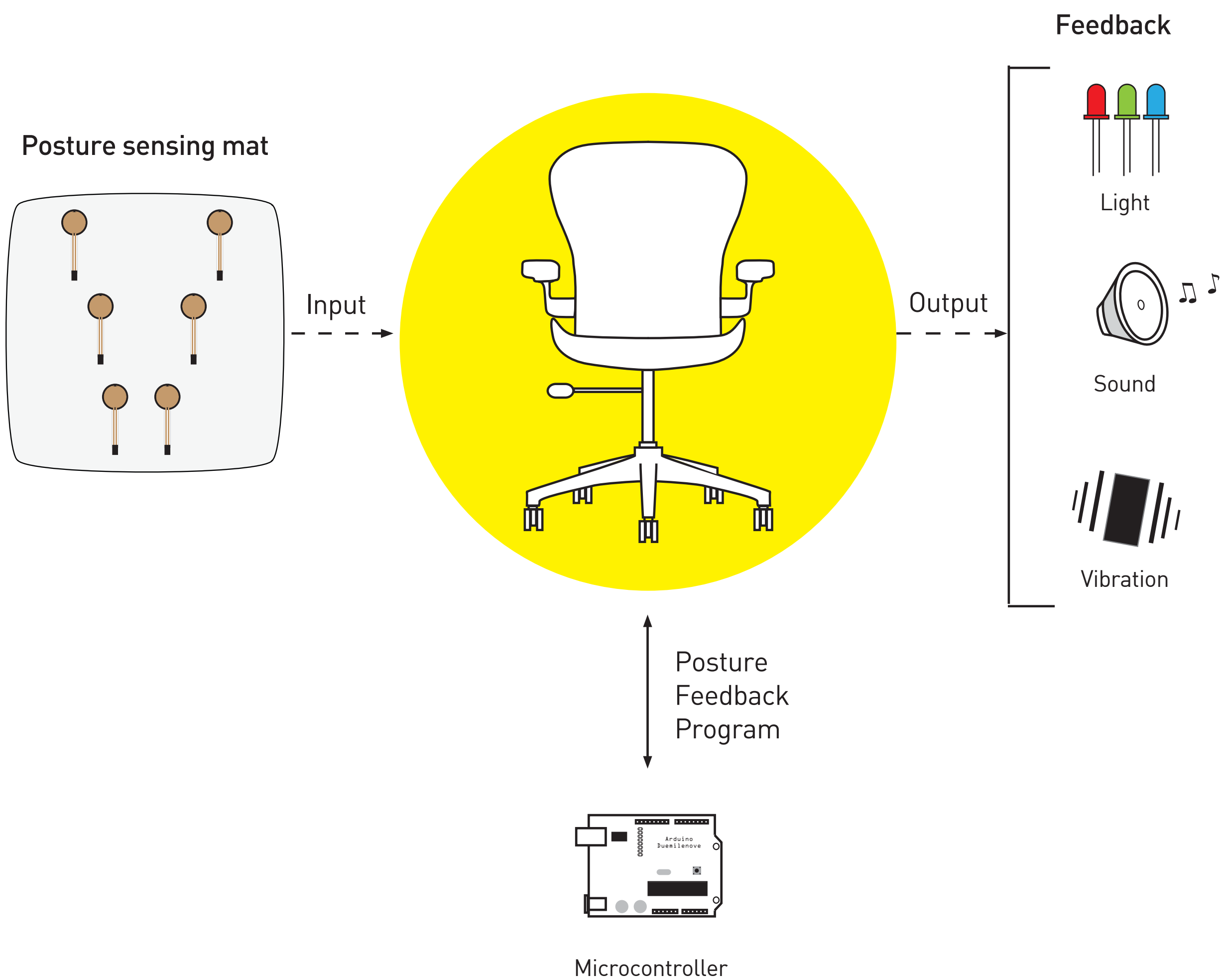

Figure 19 :System diagram of the second version of the prototype

The first model of the sensing mat was made of three layers of fabric. The top most layer is a cotton-polyester mesh, the middle layer that resembles a plastic, more rigid mesh-like fabric and the bottom-most layer is neoprene. The sensors were sewed into the middle layer with clear thread.

(See fig.20)

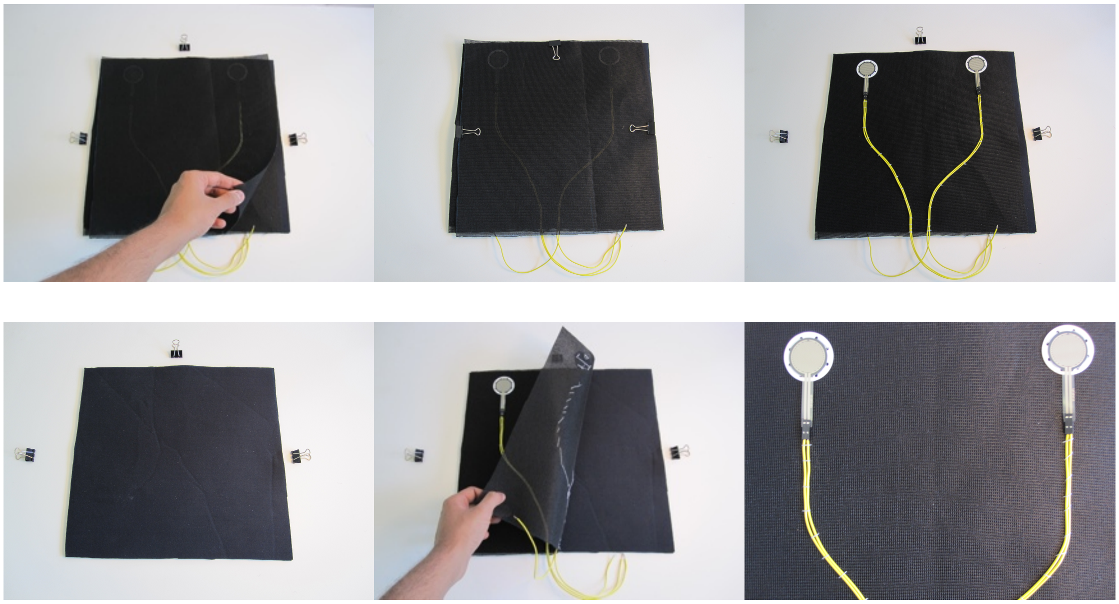

Figure 20 :Construction of the second posture sensing prototype

For the second model , several new fabrics were experimented with to improve the design of the mat. After much experimentation, leather was picked as the material of choice for the topmost layer because it bore a close relationship with regular furniture upholstery, while felt was used for the bottom layer to ensure the mat stayed in place when sat on, without slipping off the chair surface. (see fig. 21)

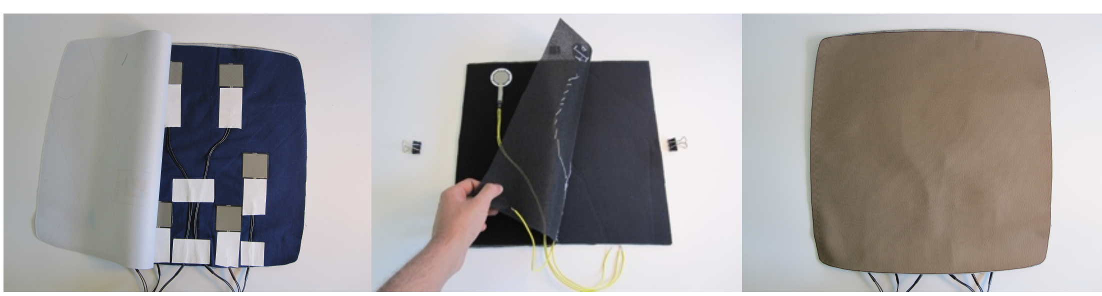

Figure 21 :Construction of the third posture sensing prototype

Figure 22 : The completed prototype used for testing

At the same time, The visual, vibratory and audio feedback prototypes were refined. The visual feedback was to be a embedded into a small physical display that could be placed by the user on his desk. On the other hand, the vibratory and audio feedback were to be place closer to the sitter's body to help him perceive it easily and also to keep the feedback personal.

2.6 Visual Feedback development.

In this system, the visual feedback is provided to the sitter for the duration of time for which static posture is maintained. When the pressure mat senses that the sitter is exerting high pressure at the seat, it starts counting the time to the time threshold is breached. The time threshold is a duration of time within which the sitter can change his/

her posture before experiencing the audio and the vibortactile feedback. Therefore the visual feedback helps the sitter pre-empt the audio and the vibrotactile feedback.

2.6.1 Location of Visual feedback & Zone of focus

When we are working at a computer our attention is absorbed by the visual display and the content on it. The area surrounding the screen and the computer makes up the zone of focus. In the zone of focus, we are highly aware of

Figure 23 : Zone of focus of a person working at a computer

any stimuli presented to us. However studies done by Haller et al [19], at the Media interaction lab shows that feedback location inside this area can obtrusive depending on the work being performed by the sitter.(See fig 24)

Figure 24 : Illustration of a person receiving postural feedback on the computer screen

This is because when at a computer, the sitter is dealing with information of varying kinds, different densities and importance on the screen. Also by nature, postural feedback information is not contextually related to the work content on screen. This makes it hard for the user to be aware of and to take immediate action on the feedback information. So the area inside the zone of focus, yet just outside of the screen, was used to provide visual feedback to the sitter.(see fig. 25)

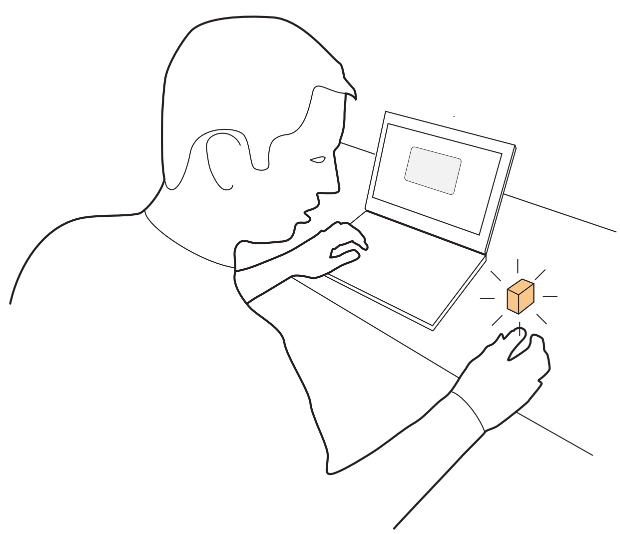

Figure 25 : Illustration of a person receiving postural feedback just outside the computer screen

2.6.2 Feedback display and visual design.

To represent the time time threshold corresponding to the duration for which, A person maintained static posture, different kinds of visual concepts were considered. (See fig. 26, 27, 28)

Concept 1 : Placement of time indicators on a linear path, horizontally

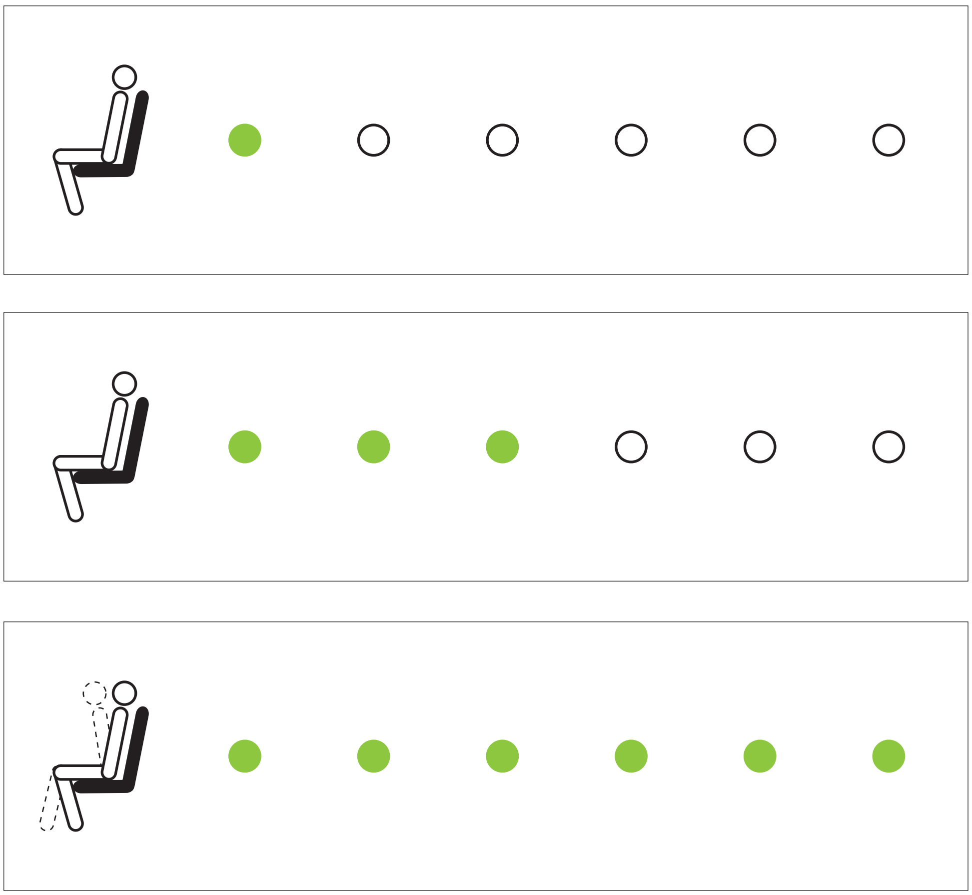

Figure 26 : Illustration of the visual feedback concept 1

Concept 2 : Placement of time indicators horizontally.

Figure 27 : Illustration of the visual feedback concept 2

Concept 3 : Placement of time indicators in a circular path, resembling a clock.

Figure 28 : Illustration of the visual feedback concept 3

All the three concepts make use of familiar symbology of Automobile dashboard icons. As is evident, the symbol in the center of the visual represents a seated person, while the passage of time is represented with the use of simple lines, circles or a circular ring around the central icon. Upon showing these concepts to some office workers, working in the vicinity, positive responses were received with regard to the third concept. To them, the circular arrangement of time elements represented the cyclical nature of time, while the central icon suggested a person sitting in a chair. Based on this data, I picked the third concept to take it forward as the visual feedback

2.6.3 Visual Feedback device form study.

The visual feedback display is an object that sits on the desk of the worker and displays postural feedback using graphics. As a part of a person's workplace, it needs to be a part of the landscape of objects on the desk, as well connected to other parts of the feedback system. Both these objectives needed to be fulfilled through an exploration of forms that could encase the visual display. (See fig. 29)

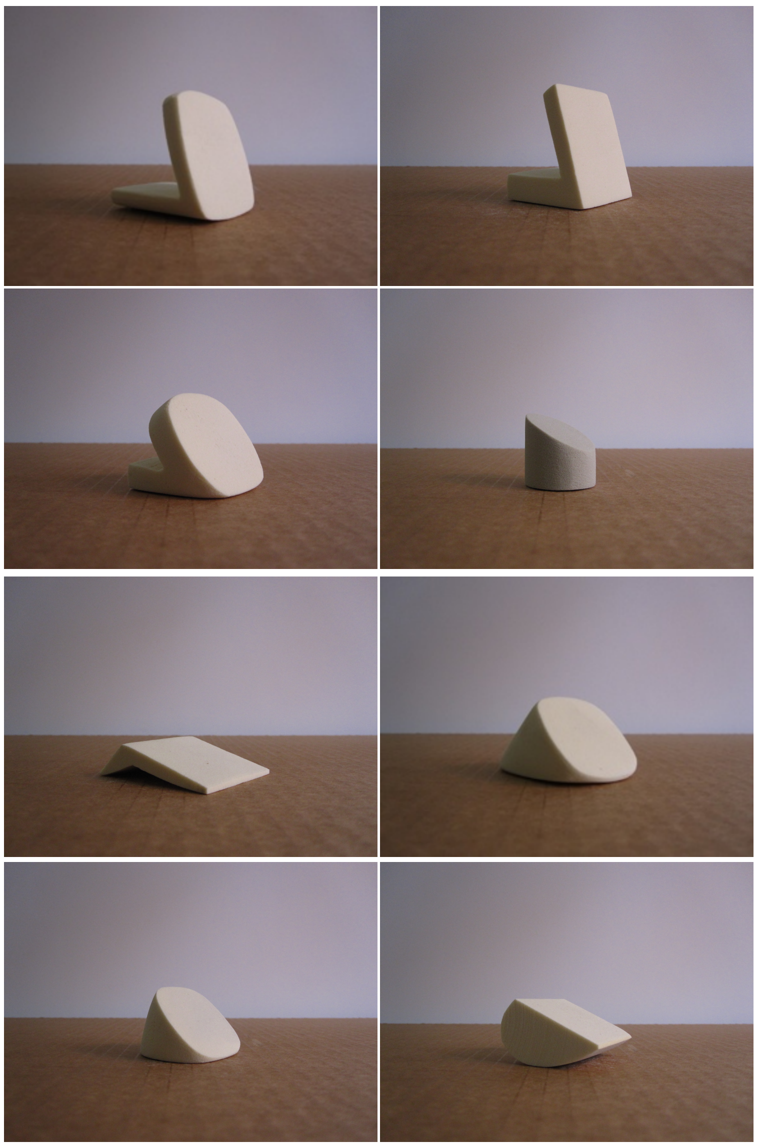

Figure 29 : Visual feedback device form explorations

2.7 Sway system Interaction scheme

Since the multimodal posture feedback system introduces new stimuli and affordances to a user of an office chair sitter, it is important to tailor them in such a way that the interaction with the chair remains very natural. Keeping this in mind, a new interaction scheme was developed for the chair that combines the use of visual, auditory and vibrational cues. Table 3 summarizes the overall scheme.

Order	Sitter Action	Sway Feedback		
		Audio	Vibration	Visual
1	Sits on the chair for the first time	None	1 subtle vibration	Awakening graphic
2	Adjusts his/her posture	None	None	Reset timer graphic
3	Does not move for less than the threshold time	None	None	Begin Timer graphic and advance visuals
4	Does not move past the threshold time	Starts	Starts	Blinking timer graphic
5	Adjusts his/her posture	Stops	Stops	Resets timer

Table 3 : The interaction scheme of the sensing-feedback system

The salient features of the scheme include

- The use of all the three kinds of feedback to inform the sitter of the need to change posture.
- The staggered flow of feedbacks, starting with the visual feedback and followed by the audio and vibrational feedback. This is done to ensure that the sitter is not over-stimulated or overloaded with too much feedback at the same time, while also ensuring that each feedback event builds on the former, gently trying to persuade the sitter to change his posture.

This scheme was tested with multiple subjects in the testing phase.

CHAPTER 3 : TESTING

The second iteration of the prototype was tested with four office workers who spend a lot of time sitting at work. To maintain privacy and confidentiality, the subjects will be referred to as Subject 1, 2, 3 and 4 instead of their names

3.1 Subject selection and characteristics

The subjects were selected based on an interview conducted before the testing session. In total seven people have been interviewed out of which four have been selected to test the feedback system.

Three out of four subjects that tested the system are female while the the other subject is male.Their age-range varies from 30 to 55 years, while their weight ranges from 105 to 224lbs, height from 5'2" to 6'3". With respect to their professions, the subjects included a researcher, a designer, a receptionist and an administrator. Based on the screening interview questions, they all work in sitting positions for an average of 6 hours per day. Two subjects said their work involves sitting intermittently - meaning sitting of and on, while the other two sit at their desks, without taking significant breaks in between. Last but not the least, all the subjects reported that their bodies were stressed due to the daily period of sitting at work.

3.2 Methodology

The objective of testing the prototype was to gather feedback on the design of the feedback system, the feedback modalities and the intensity of feedback.

The testing setup comprised of the functional prototype of the sensing- feedback system installed on a regular office chair. The chairs that subject's used regularly could not be used for testing because of structural limitations of the prototype.Specifically, the posture mat had wires that needed to connect to a microcontroller at the rear end of the seat pan. This was not possible with the subjects chairs.

3.3 Preparation

The integrated setup was then provided to each subject in place of their own chair and were asked to adjust the chair's height to suit their comfort. The the sensing system was manually calibrated to reflect the weight of the subject. This was done by making the subject sit on the chair once and using the input from the sensors to manually program the value of the pressure beyond which, the system would begin detecting the "static-ness" of any posture. The idea being that if pressure exerted by the sitter exceeds a certain value, termed as the pressure threshold, it is detrimental to the compresses tissues in the buttock-thigh. The value of pressure threshold changed with each subject as they all had different body weights and types causing them to exert different pressures at the seat-body interface.The pressure threshold was calculated by trial-and-error, by manually registering the pressure values that were generated when the subject first sat on the chair.In the later iterations of the sensing system, the pressure threshold could be automatically calculated.

The second part of the preparation was to program the sensing system to generate feedback at the appropriate time for the subject. This means that the feedback is generated only when static posture is detected and also is immediately withdrawn when posture change occurs. This element of time is determined mostly by the duration for which the the exertion of high pressure (and consequently static posture) on the body can be ideally tolerated. Ideally this duration would be as little as possible. However for the purpose of testing, the value of time threshold for generation of feedback varied with each subject as given below.

Subject #	Time threshold for static posture
1	1 minute
2	6 minutes
3	2 minutes
4	2 minutes

Table 4 : The time threshold values used in testing sessions for different subjects

The values of 1, 2, and 6 minutes were chosen based on the feedback given by the subjects on an ongoing basis. The feedback system triggered the sound, light and vibration if the sitter maintained static position for more than their corresponding time threshold minutes. The duration of the test was about 45 minutes.

3.3.1 Pre-testing Interview

Before the test began the subjects were asked to fill out a questionnaire to know more about their sitting habits and the nature of the work they do. Based on their responses, the following observations were made

1. All of them spent more than 6 hours a day at work sitting.

2. Their work required them to sit at a stretch, meaning prolonged sitting without regular breaks.
3. They all expressed that their bodies were stressed from sitting in the chair daily.
4. When asked as to what they did to address the stress from sitting, they gave with the following responses - taking frequent 5 minute walks, uncrossing and crossing one's legs while seated. Stretching and walking frequently
5. WIth respect to changes in the work area that could help in reducing the stress, all of them expressed that a better or a more ergonomic chair would help , in addition to height adjustability in their desks so they could work while standing.
6. All of them sought to be more comfortable when sitting so they could perform their jobs better. Using the mouse for long periods of time cause them a lot of pain and one subject also feared getting the carpel tunnel syndrome.

3.4 Results of the testing :

All the four subjects expressed enthusiasm when asked to test the feedback system and were comfortable using it. Based on the testing session data, in all the cases, the feedback generated was able to trigger a change in their posture or even a small rest break. Using the video captured from the testing sessions, the frames containing the posture change movements of the various subjects were extracted. It might be interesting to note that, while the time threshold and pressure threshold varied between the subjects, All of them received the feedback of the same intensity. Yet they all exhibited different ways of changing their posture. (See Fig. 30)

Figure 30 : The posture change movements shown by different test subjects

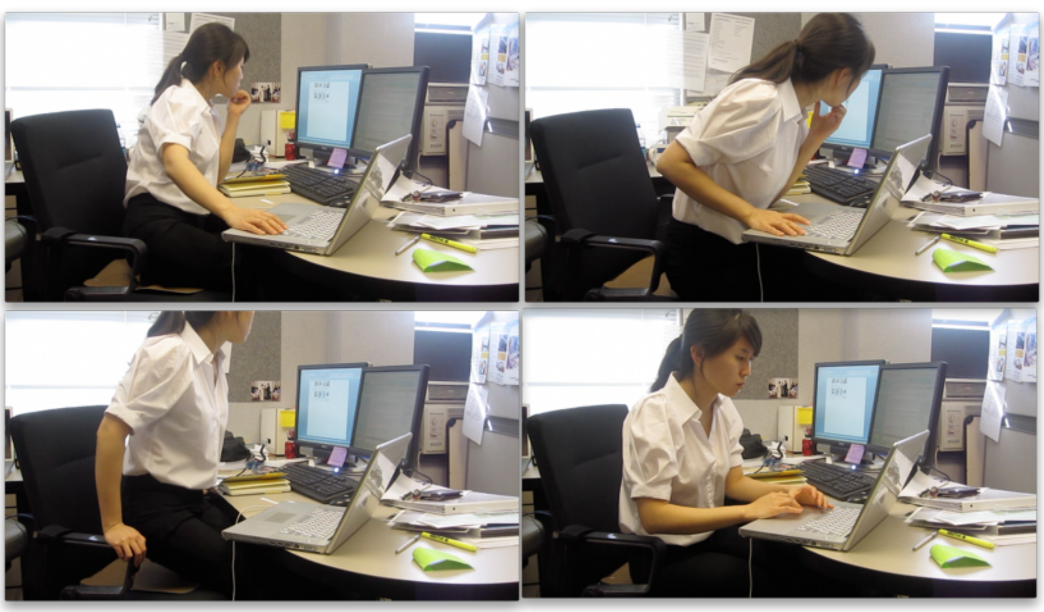

Figure 30 continued

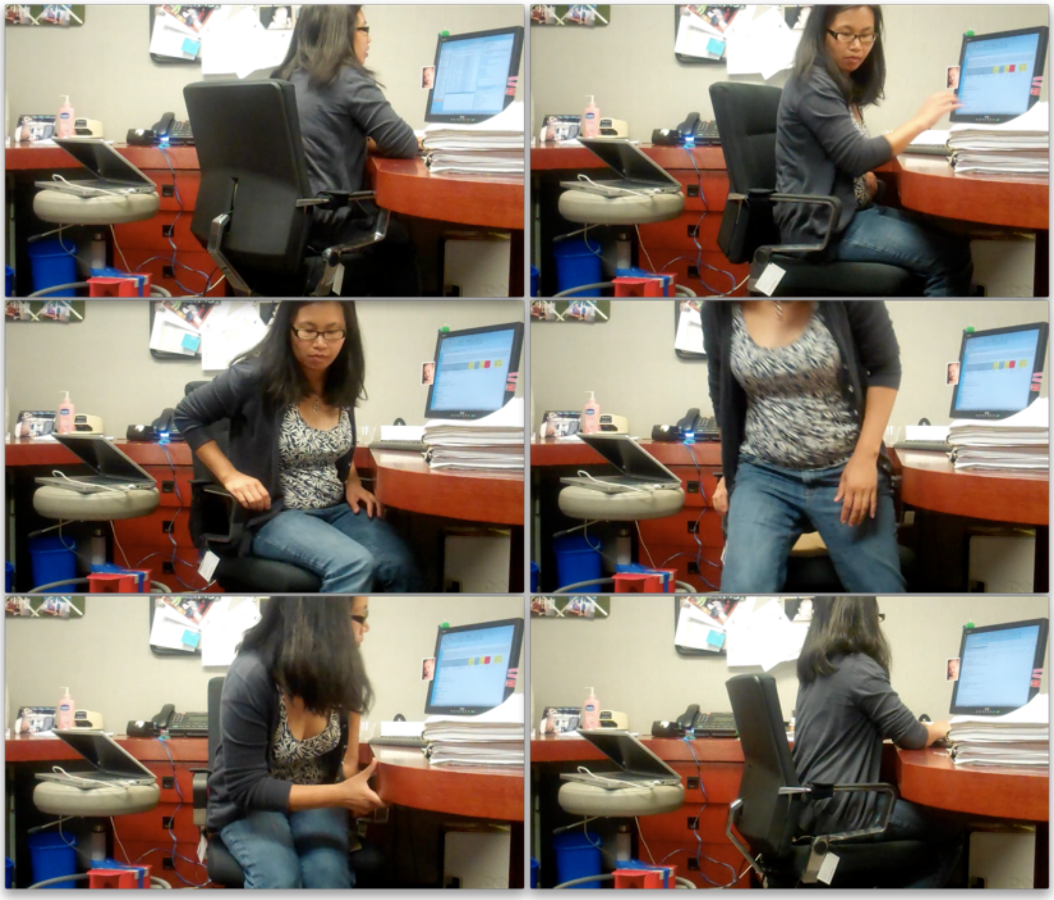

Figure 30 continued

3.4.1 Posture change frequency

The frequency with which the subjects changed their posture is a direct indication of the efficacy of the feedback system. Even though the subjects were of different body types, ages and genders, they changed their posture almost always immediately after the feedback was provided. The video from the testing session was marked every time the subject relieved the pressure and reset the notifications from the feedback system. Subject 1 had the highest number of posture changes because of receiving most frequent feedback (1 min of time threshold) while subject 3 had the least number of posture changes because of having a higher time threshold. (see fig.31)

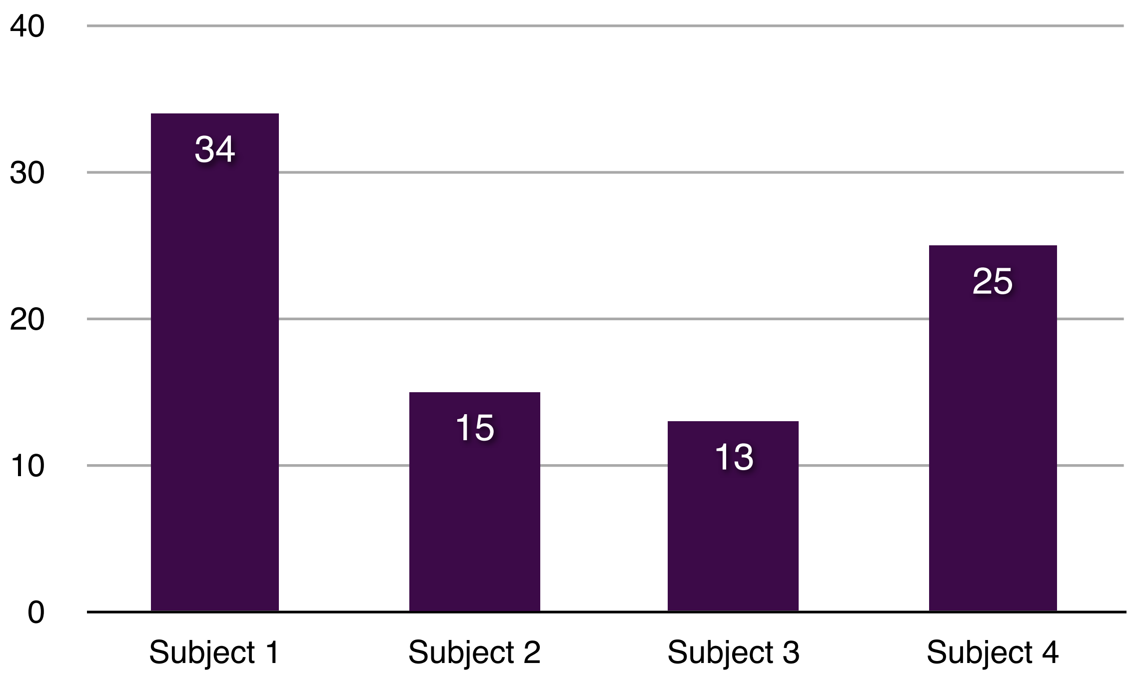

Figure 31 : The comparison of the frequency of posture change exhibited by the test subjects

<u>3.4.2 Preference of feedback mode</u>

After the testing session, the subjects reported that they liked to have postural feedback presented to them via different modes - sound, audio and vibrational .But among the three modes of feedback,all the subjects preferred visual feedback the most, followed by auditory feedback and finally vibrational feedback. Vibrational feedback was often termed bothering, annoying and distracting because of its intensity, frequency and ability to break concentration while working. None of the subjects were able to sufficiently feel the vibrations through the seat and the armrest, but were almost always able to hear the sound generated by the vibration motor. However, while the subjects described the feedback as bothersome , none of them wanted it to be removed from the system. They deemed it useful in situations where they could not look at the visual feedback. but could hear the vibrational feedback. Instead they wanted to have the ability to adjust the intensity and frequency of vibrational feedback.

3.4.3 Comfort in using the feedback system

When asked to give feedback about their experience using the feedback system, all the four subjects described it as comfortable to use. However it was noticed that the posture mat could not sense the posture changes and adjustments of a smaller magnitude making it necessary for the subjects to raise their bodies physically upwards from the seat in order to reset the feedback system. This action was physically much harder for subjects with higher body weight as well as for all the subjects when they were highly engaged in their work.

3.4.4 Pre-empting and avoiding the feedback

After the first few times of experiencing postural feedback the subjects began to anticipate it and tried to take preemptive actions such as getting up from the chair even before the vibrational and audio feedback were triggered. Another way of pre-empting the feedback was to constantly check the visual feedback device to know how soon the feedback would be triggered.

3.4.5 System's physical construction and placement

All the subjects were given the choice to place the visual feedback at a location on their desk where they could glance at it easily. The vibrational and auditory feedback devices were installed on the armrest of the chair and behind the chair respectively. None of the subjects were fully satisfied with the placement of the vibrational feedback device on the armrest as they could not perceive the vibrations. Some suggested placing it closer to their body and one subject in particular tried wearing the vibrational feedback device on her leg to gauge her comfort. The visual feedback device was received very well by all the subjects, with the only suggestion for improvement being the change of one of the led's that glowed less brighter than the others. The subjects gave highly positive responses to questions regarding its construction quality. All of them liked the use of leather on the mat because it felt comfortable to sit on it.

CHAPTER 4 : DESIGN

Based on the feedback given by the subjects during the testing session, a final model of the feedback system was developed. The model consisted of three objects - the sensing mat, the visual feedback device and the vibrational feedback device. The feedback devices were modeled to reflect their envisioned physical form. While the visual feedback device was modeled to be placed on a desk, the vibrational feedback device was modeled to be worn on the clothing of the sitter or to be attached to the chair with use of adhesive or velcro. (See fig. 32)

Figure 32 : The final representative model of the sensing-feedback system

CHAPTER 5 : CONCLUSION AND FUTURE WORK

Overall the design of the feedback system was well received but based on the testing and the responses from the subjects regarding the nature of feedback, and the feedback devices, I feel that there is still room for further design improvements.
Specifically, here are some ideas for the future iterations of the postural feedback system.

1. The mat should be able to automatically calibrate the sensing software to the sitter based on input given by the sitter at the first time of sitting using the sitters body weight. The sensing system could then use this to suggest a recommended time threshold beyond which the sitter should not maintain static posture.
2. The posture sensing system also needs to be much more sensitive to micro-adjustments in posture that relieve pressure in the buttock-thigh area and classify those movements as postural changes.
3. As stated earlier, the feedback system needs to be able to be adjusted by the user. By allowing the sitter to control the intensity of feedback received by him, the system would allow for more sustained use by the sitter .
4. In its current form, the posture sensing mat is connected to a rigid-micro-controller that is placed outside its body. This necessitates the use of long wires to connect them both resulting in weak construction and reduced reliability in installation. To solve this problem, the micro-controller circuitry could be integrated into the posture sensing mat itself and be provided wireless networking capabilities to communicate data to a control module . This will eliminate all the visible wires in the system and improve the

quality of the mats construction. This will also make the overall sensing-feedback system , a three part product that is much more portable to carry and use with multiple chairs.

5. The materials used for the construction of the mat could use further exploration to increase the comfort, wear resistance and breathability of the fabric. This will allow for robust use of the mat.
6. The physical design of the feedback devices has not been tested to gauge the comfort, perception and ease of use of office workers intending to use it. The physical form of the device needs more exploration and refinement in order to be designed and ready for manufacture.
7. The system should be tested with more people to get a better idea of the improvements made to the sensing system.

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